MOBILE EXPERTS

EXPERT INSIGHT FOR RAN and Handset Subscribers

Massive MIMO Testing:

A game changer?

Introduction

Massive MIMO will turbo-charge the mobile network, adding much higher spectral efficiency and therefore much higher capacity. Every major OEM and operator in the industry agrees that massive MIMO will be a part of the future network.

This is one of those cases where a technology decision impacts the supply chain dramatically. One of the most meaningful changes will be the physical construction of the radio. Instead of the usual RRH box with CPRI on one end and 50 ohm RF connectors on the other end, we now have an integrated antenna radio (IAR) with a fiber coming in and antennas radiating RF on the other side.

Engineers have talked about the benefits of integration between the PA, LNA, and antenna for 20 years or more, and several products over the years have been promoted to bring the benefits to market. In the end, most of these products in the 2G to 4G market have been ultimately unpopular, due to reliability concerns on the tower-top, limited band coverage, the inflexibility of the radio/antenna combination, and the overall heft and bulk of the box.

Massive MIMO provides enough benefit to overcome these objections, and it's clear that the technology is moving forward with integrated radios. In the millimeter-wave frequency bands, electrical loss will force integration of antenna and radio components in both infrastructure and handset areas.

This *Insight* document is intended to show the impact of beamsteering on the infrastructure and device markets, because major changes will impact both sides. Each type of product will be considered separately….but of course both infrastructure and client devices must be available for the overall market to succeed.

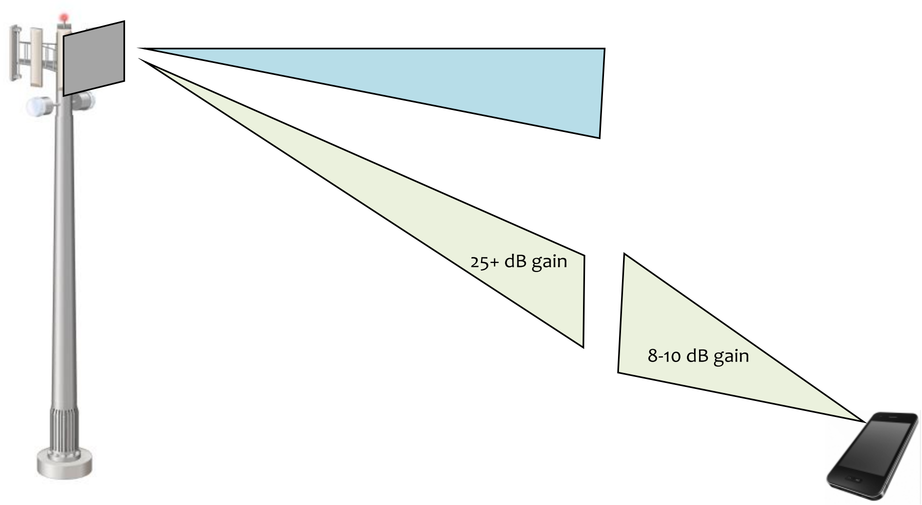

Figure 1: 5G links depend on high-gain antennas on both ends

Source: Mobile Experts

Note: A handset is shown here but in reality many types of UE devices are considered

INFRASTRUCTURE: Change to Physical Configuration:

The most obvious impact of the massive MIMO feature is that the radio will be integral with the antenna array. There are two important cases to consider:

1. At millimeter-wave frequencies, each antenna element and its corresponding filter/PA/LNA/switch will need to be very tightly integrated. Coaxial connectors exist for testing at 28 GHz and 39 GHz, but there's no room for them in this configuration. More importantly, there's no allowance for the insertion losses that would be introduced by making space for the connector.

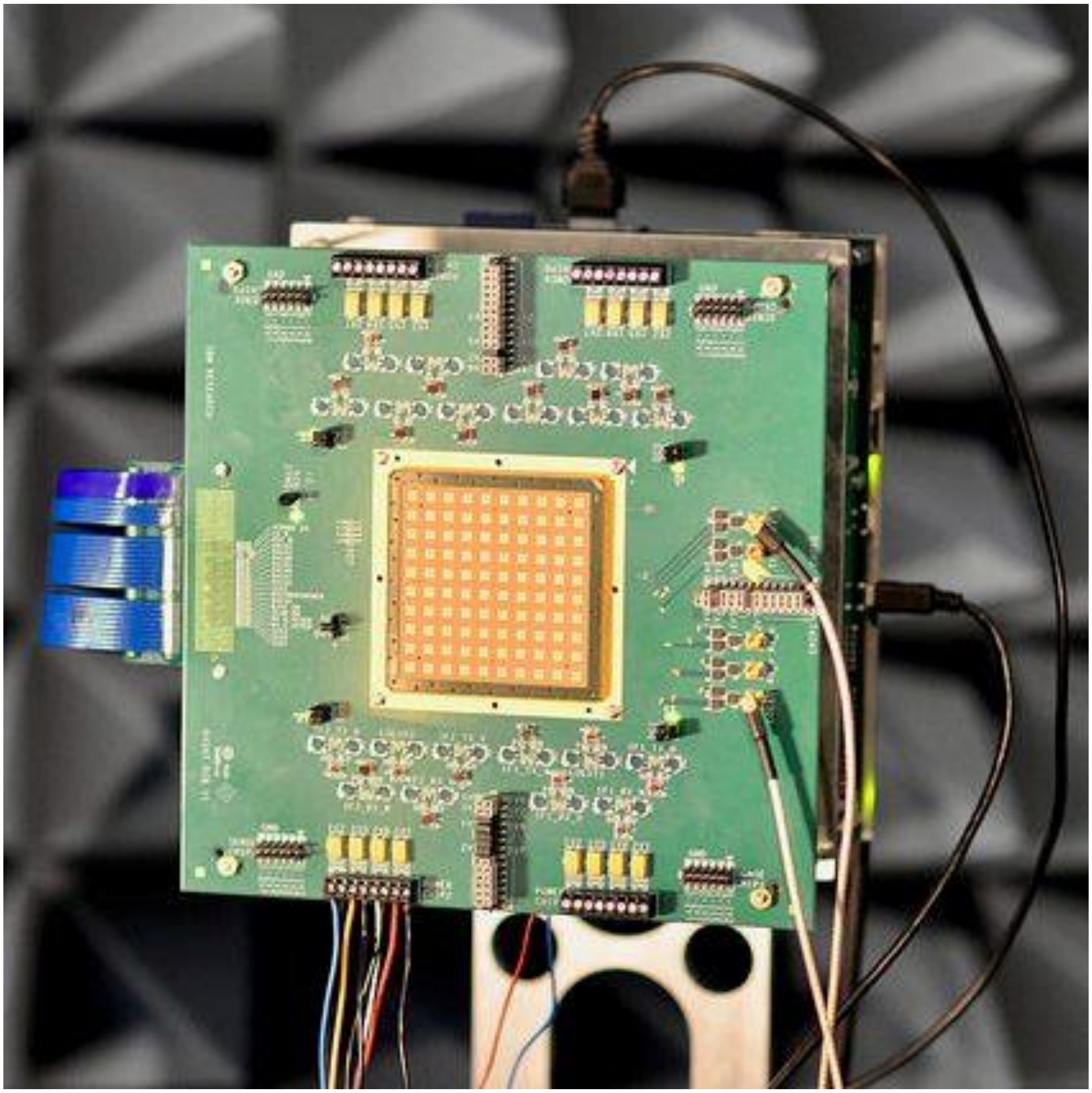

Figure 2: A 28 GHz active antenna array

Source: IBM/Ericsson

2. At lower frequencies, there may be enough space for a connector, but the practical use of connectors would create problems. Imagine that you're the poor technician that has to fumble with 128 small blind-mate connectors—or even worse, 128 individual cable assemblies for testing. Just verifying a solid connection for all 128 paths could take significant time.

In fact, below 6 GHz, the massive MIMO radio head is expected to be highly integrated as well, with power amplifiers, switches, LNAs, and filters integrated into a small RF module that sits behind each active antenna element. Major OEMs do not plan to include separate connectors.

Figure 3. Massive MIMO array below 6 GHz

Source: Kathrien-Werke

INFRASTRUCTURE: Manufacturing Impact:

Today's macro RRH utilizes a series of discrete components, including LDMOS or GaN amplifiers in bulky ceramic or other packages, duplexers or cavity filters, and separate RF components such as LNAs or switches in discrete form. Each component is tested on a 100% basis by the component supplier, and the board is tested 100% for spurious emissions, desensitization, sensitivity, and other parameters at the board level.

Integration for massive MIMO involves two changes in manufacturing:

- Each RRH will include a lot more transceiver elements, so the power amplifiers will not handle high power for each RF path. Instead of optimizing with separate discrete components, the OEMs will be integrating the RF components into modules, with PA/switch/LNA function in one tidy module.

- The antenna will be mounted on top of each RF front-end module with minimal distance and loss between the RF amplifiers and the antenna radiator. This is a major change from the surface-mount component placement of the past, because the antenna elements are three-dimensional structures. The capital equipment and manual skills involved will be very different.

INFRASTRUCTURE: Testing Considerations:

When we get our Integrated Antenna Radio together, it's time for testing. Today's systems are shipped to the field with exhaustive 100% testing on the RRH box (using a connector) and also with 100% testing of the antennas (in chambers). The RRH testing can require about 15 minutes in a factory setting, and the antenna can require another 5 minutes for each port in production testing. The pair are assumed to work well together, as the RRH and antenna see each other for the first time on their wedding day.

On the other hand, with massive MIMO, the combined test will require more time. Beam-steering is likely to be tested in five beam locations or more (at least in the beginning of the production life cycle), resulting in a test process ranging from 30 to 60 minutes. Other parameters must also be tested, including spurious emissions, EVM, and desensitization.

The longer test time will be extended even farther if any FDD band coverage is required on the antenna panel. While most massive MIMO requirements are specified in TDD bands now, some operators want a massive MIMO panel that also handles their existing FDD bands. They want to avoid an additional antenna box, because more boxes results in more cost in rental fees to the tower owner, higher wind load, etc.

Unfortunately, adding FDD bands will create a need to test for Passive Intermodulation (PIM), which is normally not a concern in the TDD world. This can triple the test time or worse, due to a need to sweep a wide frequency band. A seemingly simple request to add some FDD antenna dipoles could double the cost of the product by adding lengthy test time.

Note that one vendor suggested the possible use of open-air testing, but that possibility is not workable. Firstly, crosstalk between two tests would be a killer. Secondly, producing American products in China would violate local spectrum assignments. Forget that option.

INFRASTRUCTURE Cost Impact:

Even if FDD and PIM issues do not arise, the cost impact of massive MIMO testing will still become a significant factor in the cost of a RRH.

Test chambers with 100 dB+ isolation are required to perform each production test. Each chamber has an odd shape to avoid internal reflections, and copper shielding covers the entire structure. Leading antenna vendors have techniques that can shrink the size of the chamber from hundreds of square meters to about 16 square meters.

Each chamber costs roughly $100,000 to set up, due to the isolation required, the mechanical assemblies and precisely calibrated internal antennas.

Significant factory floor space will be required for major-league production testing. To produce 1 million RRH units per year, a factory must produce about 115 units per hour. (This estimate assumes no rework/retesting, and 24/7 operation). With a 75-minute test cycle, and about 20 square meters per chamber, the testing area will be at least 3000 square meters. In some production arrangements, one technician can manage multiple automated test fixtures. But due to the long distances between test stations, that labor-saving approach is unlikely for massive MIMO.

The cost impact: the capital investment for a production factory will include more than $10M of new capital cost, plus conversion of existing factory floorplans and test equipment for the 5G requirement. The cost of testing a 5G RRH could be about 6X the cost of testing a 4G RRH… still a minor element in the overall cost, but it's becoming more significant overall.

INFRASTRUCTURE: Time to Market Impact:

While the cost impact might be relatively small, the challenges in ramping up a new form of manufacturing could be a killer for a radio manufacturer. Companies like Nokia and Ericsson are set up to produce PCBs with connectors, not three-dimensional structures with precise alignment of mechanical antenna elements. Setting up the actual manufacturing line from scratch is likely to result in surprises and slowdowns.

One possibility will be for the major OEMs to partner with leading antenna manufacturers (such as Kathrein-Werke or Commscope) to construct and test the RRH. This could be a major strategic opportunity for these companies to elevate themselves as the trusted supplier of the radio hardware for the entire network.

CLIENT DEVICES: Change to Physical Configuration

Today's handsets, tablets, and IoT devices use relatively simple antennas to optimize efficiency for a given band. No antenna steering is used in the LTE market for mobile devices. This architecture is likely to continue for 5G NR systems that will be introduced in the 3 GHz to 6 GHz range. 2x2 or 4x4 MIMO will be the rule, without any beamsteering for additional gain in the link budget.

However, millimeter-wave networks will need help in the link budget. In the downlink, the base station will be limited to about +47 dBm due to thermal constraints in amplifiers and processing at the RRH. That means that achieving long-distance links will depend on achieving some gain in the client device. Verizon's fixed broadband network relies on a CPE that has about 10 dB of gain, in order to achieve reasonable SINR for good downlink performance.

At the same time, the uplink will be limited. A CPE is not necessarily limited in power consumption, but will be limited to a smaller number of transmitter elements than the base station. SOI or SiGe amplifiers will only provide about +15 dBm (or thereabouts) per element, so a sub-array with 8 elements will not be powerful enough to reach hundreds of meters to close the link. Handheld devices like tablets and handsets have even bigger issues, because the amplifiers at 28-39 GHz are so inefficient.

In short, we don't expect beamsteering below 6 GHz, but we do expect that 5G client devices at 28+GHz will include some form of beamsteering.

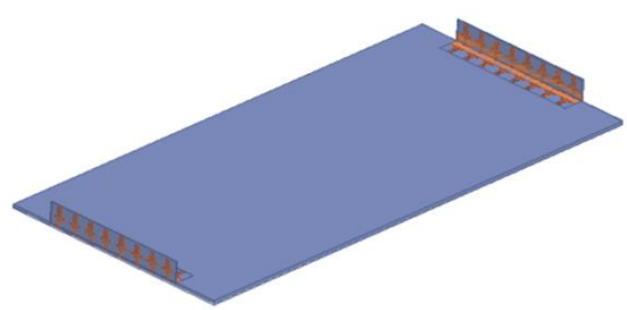

Figure 4. One possible implementation of a beamsteering array in a handset form factor

Source: Shanghai University

The market will start with CPEs that are large, with high power consumption and fairly expensive implementation of antenna subarrays. However, as mobile 5G becomes important in Korea at 28 GHz and later in Japan or possibly the USA, tablets will come next.

It's important to note that any handheld device will have issues in the millimeter-wave bands with attenuation from the user's hands.

CLIENT DEVICES: Manufacturing Impact:

Below 6 GHz, we don't expect any meaningful change, as noted above. However, above 24 GHz we expect that handsets must change dramatically. There are multiple aspects to this:

- Handsets, tablets, and IoT devices are all specified and approved by regulatory agencies based on conducted testing today. That means that client devices are *not optimized for radiated performance* because they're simply not evaluated on radiated performance. The design will be more optimized to true link performance as the OEM's internal processes align to consider the antenna performance in overall system architecture.

- Antennas are purchased as a part of the industrial design (along with the plastic or metal case), and are not subject to very stringent test requirements in most cases. The antenna design will become a part of the electrical design team's responsibility, not the industrial design responsibility.

- The physical space set aside for antennas in a typical smartphone is a small, convoluted area on each end of the handset. For a beamsteered millimeter-wave radio, the space set aside must be larger to accommodate multiple elements. The elements will be small, but they must be spaced apart to avoid blocking the mm-wave signal with the user's hand. The antennas must also be arranged on more than one plane for three-dimensional beamsteering. All of this takes space.

- Client devices are typically designed today, then at the last minute an antenna requirement is communicated to antenna vendors. The mechanical envelope and other physical requirements for the antenna are often not known until the last stages of handset development, and in fact the antenna vendor often has only about 3 weeks to create an acceptable design before moving to the production phase. This timeframe absolutely will need to change, with a larger space set aside for the beamsteered antenna. Overall time to market for a smartphone or similar product will probably become much longer.

CLIENT DEVICES: Testing Impact:

Production testing of a handset, tablet, or IoT device is pretty quick today. The device is placed in a fixture, then a series of spot tests are performed on a connector, then the antenna is screwed into place and the product is shipped. There is no 100% production testing at a radiated level today.

First of all, the test fixture must change. To achieve a far-field measurement, an isolated chamber in the range of 3-4 meters long will be necessary, even for a very small device. This means that producing millions of devices will be more capital-intensive and will require a large floor space for the test itself. Assuming a 15 minute test, producing a million handsets per week could require a huge factory floor of more than 30,000 square meters. Batch testing of multiple devices or other clever tricks are likely to be used to reduce the capital and floorspace requirements.

Secondly, the test time could be extended dramatically. Today's devices are tested at a few frequencies with worst-case conditions to verify performance. A beamsteered device must be tested for these same frequencies at worst-case voltage and power levels, but then these tests will need to be repeated for the 28+ GHz link to verify adequate performance in at least two or three additional beamsteering conditions. It's three-dimensional beamsteering in any portable device, so six test beams would be a likely case.

Without doubt, the test engineers that oversee production testing for smartphones will be able to reduce the impact with highly streamlined quality processes.

To keep things in perspective, the 5G link will only be included in a niche product offering during the next 5 years, and it will only be one frequency band among 25 others. For multiple reasons, we expect the 5G mm-wave client devices to be a small part of global production….it simply will be a big disruption to the entire process of designing, building, and testing a smartphone, so the main smartphone market will not adopt mm-wave 5G very quickly.